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Characterization of bioresidues for biooil production through pyrolysis

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HIGHLIGHTS

- 1st report on biooil production from *Melia Dubia*, *Polyalthia longifolia*, Raintree fruit.
- TGA guided pyrolytic temperature.
- Model developed to correlate the composition of bioresidues with biooil production.

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ABSTRACT

Biomass is a renewable resource utilized to produce energy, fuels and chemicals. In this study, 25 bioresidues were selected and the physical, chemical, thermal and elemental analyses of the residues were studied as per standard methods. The bioresidues were pyrolyzed at 450 °C in a fixed bed reactor to produce biooil. Among the residues, paper (pinfed computer) and Parthenium produced maximum (45%) and minimum biooil (6.33%), respectively. Arecanut stalk, redgram stalk, rice husk, wheat husk, maize cob, coir pith, Cumbu Napier grass Co5, Prosopis wood and paper resulted in a better biooil yield. Models were developed to predict the effect of constituents of bioresidues on the yield of biooil. The volatile matter and cellulose had significant effect on biooil yield. Biooil thus obtained can be used as fuel that may replace considerable fossil fuels.

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1. Introduction

Fossil fuel shortage and severe environmental problems have drawn more attention on the utilization of clean renewable energies. Biomass is one of the promising renewable energy resources and can be a partial alternate to fossil fuels. The use of biomass can reduce the dependency on the limited fossil fuels and has the advantage of reduced net CO_2 emissions. Biomass includes various natural and derived materials, such as woody and herbaceous species, wood wastes, energy crops, agricultural and industrial residues, waste paper, municipal solid waste, grass, waste from food processing, animal wastes, aquatic plants and algae etc. Generation of these residues is increasing every year but due to their lesser advantages, the residues have not found any remarkable application and have negative market value (Pallav et al., 2006). The current availability of biomass in India is estimated about 120–150 million tons per annum corresponding to a potential of 18602 MW of electricity generation (Ministry of New and renewable energy, 2010). Utilization of these residues for energy generation and value addition by different thermo-chemical processes may replace a significant portion of the conventional energy sources for fuel, energy and chemicals supply.

Pyrolysis is one of the thermo-chemical processes carried out in the absence of oxygen. It yields carbon-rich char, condensable vapors and non-condensable gases. The condensed vapor referred as biooil – a dark brown liquid, can be used in boilers, diesel engines for power generation to replace fossil fuels. It can also be a chemical source with more than 300 organic compounds. It has environmental benefits as a clean fuel and causes less pollution as compared to fossil fuels (Churin and Delmon, 1989). In this study, various bioresidues were selected and their suitability to produce biooil with a higher heating value was investigated.

2. Methods

Utilization of lignocellulosic material as feedstock faces problems due to their complex structure and the difficulty to separate their components in an economically feasible way (Meier and Faix, 1999). In this study, 25 lignocellulose materials such as agro-residues, energy crops, grasses, wood and weed were selected to carry out the biooil production. It includes arecanut stalk, cotton stalk, redgram stalk, soybean stalk, paddy straw, arecanut husk, jatropha husk, rice husk, wheat husk, cashew nut shell, coconut shell,

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Table 1
Proximate composition of selected bioresidues.

Sample	Moisture (%)	Volatile matter (%)	Fixed carbon (%)	Ash (%)	Density (kg/m^3)
Arecanut stalk	9.80 (0.03)	68.70 (0.26)	15.60 (0.06)	5.90 (0.05)	270.30 (7.50)
Cotton stalk	10.20 (0.05)	62.07 (0.30)	19.53 (0.02)	8.20 (0.09)	321.50 (2.30)
Redgram stalk	5.91 (0.10)	72.09 (0.84)	11.38 (0.90)	10.62 (0.1)	257.20 (5.20)
Soybean stalk	11.84 (0.85)	58.43 (0.30)	16.14 (1.20)	13.59 (0.5)	263.50 (7.90)
Paddy straw	8.66 (1.40)	65.47 (0.20)	10.37 (0.40)	15.50 (0.8)	272.0 (6.80)
Arecanut husk	12.50 (0.09)	62.97 (0.07)	18.93 (0.30)	5.60 (0.80)	298.40 (4.80)
Jatropha husk	11.30 (0.23)	60.70 (0.01)	13.70 (0.40)	14.3 (0.20)	283.80 (9.60)
Rice husk	5.83 (1.02)	73.80 (0.14)	15.80 (0.60)	4.57 (0.90)	510.10 (7.40)
Wheat husk	13.90 (0.97)	68.10 (0.80)	16.40 (0.60)	1.60 (0.80)	369.20 (9.50)
Cashew nut shells	6.93 (1.49)	70.44 (0.91)	14.73 (0.43)	7.90 (0.60)	231.60 (6.64)
Coconut shell	4.40 (0.02)	71.99 (0.20)	19.79 (0.09)	3.82 (0.50)	293.90 (11.9)
Tamarind shell	8.44 (0.32)	68.56 (0.06)	13.44 (0.91)	9.56 (0.30)	302.30 (8.40)
Maize cob	15.20 (0.80)	64.80 (0.50)	16.69 (0.4)	3.31 (0.94)	319.0 (12.10)
Sugarcane bagasse	8.50 (1.20)	70.04 (0.03)	13.44 (0.07)	8.02 (0.06)	293.0 (5.93)
Coir pith	9.65 (0.50)	69.35 (0.4)	15.44 (0.50)	5.56 (0.01)	415.90 (7.38)
Saw dust	7.01 (0.06)	73.0 (0.08)	14.04 (0.09)	5.95 (0.10)	792.80 (4.80)
Cumbu Napier grass Co5	7.07 (0.91)	71.43 (0.20)	18.47 (0.40)	3.03 (0.02)	236.0 (6.90)
Blue buffel grass	10.14 (1.30)	69.47 (1.05)	9.93 (0.20)	10.46(0.14)	294.0 (8.40)
Polyalthia longifolia	8.86 (0.20)	61.64 (0.50)	16.39 (0.83)	13.11 (0.4)	265.10 (9.20)
Melia dubia wood	9.80 (0.90)	65.82 (0.44)	16.77 (0.20)	7.61 (0.06)	258.50 (10.1)
Prosopis wood	7.77 (0.02)	71.25 (0.56)	15.11 (0.91)	5.87 (0.01)	690.30 (11.8)
Samanea saman fruit	3.47 (0.02)	75.27 (0.08)	16.96 (0.50)	4.30 (0.40)	287.43 (8.90)
Chlorella	9.05 (0.40)	62.20 (0.6)	16.19 (0.30)	12.56(0.06)	373.60 (7.30)
Parthenium *hysterophorus*	6.08 (0.80)	69.14 (0.02)	10.31 (0.93)	14.47(0.01)	269.30 (9.40)
Pinfed computer paper	8.26 (0.80)	79.14 (0.40)	7.24 (0.66)	5.36 (0.40)	246.0 (6.90)

The values in parenthesis are standard deviation at 95% confidence interval. Number of determination is 3.

Table 2
Elemental composition of selected bioresidues.

Sample	C (%)	H (%)	O (%)	N (%)
Arecanut stalk	47.12 (0.84)	5.95 (0.44)	43.54 (0.43)	3.39 (0.60)
Cotton stalk	46.77 (0.50)	5.76 (1.09)	41.71 (0.82)	5.75 (0.93)
Redgram stalk	44.11 (1.20)	5.69 (1.84)	41.97 (0.37)	8.23 (0.70)
Soybean stalk	43.61 (0.19)	5.45 (0.02)	44.66 (0.29)	6.28 (0.57)
Paddy straw	41.62 (0.14)	5.39 (0.93)	45.12 (0.07)	7.87 (0.73)
Arecanut husk	47.89 (0.94)	5.93 (0.40)	43.10 (0.18)	3.08 (0.68)
Jatropha husk	42.82 (0.65)	5.43 (0.33)	46.34 (1.27)	5.41 (0.94)
Rice husk	47.79 (0.88)	6.04 (0.69)	44.16 (0.40)	2.02 (0.56)
Wheat husk	48.29 (0.90)	6.22 (0.88)	44.87 (0.25)	0.62 (0.79)
Cashew nut shells	46.02 (0.19)	5.83 (0.42)	42.71 (0.32)	5.44 (0.03)
Coconut shell	48.88 (0.40)	6.05 (0.36)	43.82 (0.98)	1.25 (0.38)
Tamarind shell	45.00 (0.33)	5.73 (0.76)	44.13 (0.76)	5.14 (0.53)
Maize cob	48.54 (1.32)	6.11 (0.65)	44.62 (1.11)	0.73 (0.09)
Sugarcane bagasse	45.72 (0.74)	5.84 (0.78)	42.88 (0.34)	5.56 (0.35)
Coir pith	47.25 (0.25)	5.97 (1.06)	43.74 (0.14)	3.04 (0.58)
Saw dust	46.81 (0.30)	5.96 (0.36)	43.79 (0.59)	3.44 (0.47)
Cumbu Napier grass Co5	49.00 (0.59)	6.11 (0.25)	44.44 (0.55)	0.45 (0.15)
Blue buffel grass	43.92 (1.19)	5.71 (0.78)	42.30 (0.89)	8.07 (1.08)
Polyalthia longifolia	47.12 (0.63)	5.95 (0.63)	43.54 (0.30)	3.39 (0.57)
Melia dubia wood	46.77 (0.03)	5.76 (0.58)	41.71 (0.76)	5.75 (0.30)
Prosopis wood	44.11 (0.76)	5.69 (0.49)	41.97 (0.03)	8.23 (0.76)
Samanea saman fruit	43.61 (0.93)	5.45 (1.12)	44.66 (0.49)	6.28 (0.35)
Chlorella	41.62 (0.59)	5.39 (0.68)	45.12 (0.82)	7.87 (0.93)
Parthenium *hysterophorus*	47.89 (0.15)	5.93 (0.76)	43.10 (0.90)	3.08 (0.81)
Pinfed computer paper	42.82 (0.53)	5.43 (0.52)	46.34 (0.48)	5.41 (0.57)

Note: Average absolute error used for carbon, hydrogen and oxygen was 3.21%, 4.79% and 3.4%, respectively of the calculated value. The values in parenthesis are standard deviation at 95% confidence interval. Number of determination is 3.

tamarind shell, maize cob, sugarcane bagasse, coir pith, saw dust, Cumbu Napier grass Co5, blue buffel grass, *Polyalthia longifolia* (False Ashoka tree leaves), *Melia dubia* wood, prosopis wood, *Samanea saman* (Rain tree) fruit, Chlorella, *Parthenium hysterophorus* and pinfed computer paper. They were selected based on the availability, low fertilizer value and higher energy content.

Paddy straw is an agro residue with a generation rate of 112 MT yr^{-1}. Most of the paddy straw is burnt in the field without any proper utilization and minimal percentage is fed for cattle. Wheat straw is used mainly as cattle feed with a production rate of 110 MT yr^{-1}. The main feed as fuel for sugar plants is from sugarcane bagasse and the production rate is 101.3 MT yr^{-1} (Sukumaran et al., 2010). Redgram stalk is generated at the rate of 9 MT yr^{-1}. Cotton stalk has no fertilizer value and partly used as domestic fuel and the generation rate is 26.2 MT yr^{-1}. The production of maize cob is 4.2 MT yr^{-1}. Coir pith (7.5 MT yr^{-1}) has found no use and disposal is the major problem. In India, coconut shell is widely used as domestic fuel and partly for making mattresses and carpets etc., Jatropha husk constitutes about 35–40% of the fresh fruit and mainly used as a feed for gasification (Vyas and Singh, 2007); sometimes left as mulch around the trees. India is the largest producer and processor of cashew and the average productivity

Table 3
Chemical constituents of bioresidues.

Sample	Cellulose (%)	Hemi cellulose (%)	Lignin (%)
Arecanut stalk	30.3 (0.50)	39.0 (5.40)	27.1 (6.20)
Cotton stalk	25.9 (3.80)	12.0 (9.23)	20.0 (2.40)
Redgram stalk	31.6 (1.20)	19.2 (4.90)	19.8 (7.30)
Soybean stalk	25.9 (0.70)	30.0 (1.24)	12.0 (2.19)
Paddy straw	23.0 (1.10)	22.4 (2.80)	18.0 (3.76)
Arecanut husk	25.4 (2.0)	35.5 (1.11)	20.8 (5.29)
Jatropha husk	24.0 (1.41)	23.8 (3.03)	21.4 (4.80)
Rice husk	35.0 (0.83)	22.4 (4.73)	14.1 (0.81)
Wheat husk	37.0 (3.90)	18.0 (7.27)	14.3 (5.70)
Cashew nut shells	30.2 (1.80)	34.0 (8.90)	43.0 (7.80)
Coconut shell	26.5 (2.31)	27.0 (6.20)	6.0 (4.28)
Tamarind shell	27.0 (0.60)	6.0 (4.30)	30.1 (0.90)
Maize cob	35.0 (3.95)	32.0 (1.80)	19.0 (1.64)
Sugarcane bagasse	29.0 (4.80)	22.0 (3.60)	21.0 (3.81)
Coir pith	32.0 (10.20)	24.0 (7.26)	42.0 (9.27)
Saw dust	27.0 (8.19)	13.0 (4.0)	45.0 (0.85)
Cumbu Napier grass Co5	31.0 (7.60)	34.0 (5.80)	23.0 (1.72)
Blue buffel grass	24.0 (5.90)	14.0 (2.19)	29.8 (7.92)
Polyalthia longifolia	20.0 (12.10)	28.3 (5.78)	20.0 (6.25)
Melia dubia wood	21.3 (3.10)	29.7 (4.72)	23.0 (8.23)
Prosopis	37.9 (7.00)	19.0 (9.17)	37.0 (0.49)
Samanea saman fruit	25.0 (4.10)	21.0 (5.29)	42.0 (3.81)
Chlorella	7.0 (6.50)	20.0 (1.69)	25.0 (2.30)
Parthenium *hysterophorus*	19.0 (3.02)	24.0 (7.29)	22.1 (4.89)
Pinfed computer paper	80.5 (1.29)	20.0 (0.81)	17.0 (10.1)

The values in parenthesis are standard deviation at 95% confidence interval. Number of determination is 3.

is 760 kg ha^{-1} (Rajesh et al., 2011). Its generation is about 762.5 MT yr^{-1}. Operating capacity of the Indian pulp and paper industry has been estimated to be 8.5 MT by the Indian Agro and Recycling Paper Mills Association. Nearly 6.5 MT of paper reaches landfills and is lost forever. Arecanut production in India is 150 MT yr^{-1} and the husk constitutes about 60–80% of the total weight of fresh fruit. It can be used as a substrate for mushroom cultivation and fluffy cushions, but due to the existence of piles of areca husk after processing in the developing countries their value is not pronounced much. Algal species exist in almost all water sources and the advantageous point about algae is its widespread availability and reduced maintenance as compared to food crops. One of the world's seven most devastating and hazardous weeds, parthenium invaded 14.25 million ha of farm land in India including crop land, wasteland and forest areas. The matured rain tree acts as a good carbon dioxide adsorbent medium and it is capable to fix the nitrogen in atmosphere (Quisumbing, 1951). Parts of the tree such as leaf, pulp in fruit and bark have their own medicinal, fodder and fuel value. On an average, the matured tree can yield 200–250 kg of pod per season. *Polyalthia longifolia* was originated from Indian subcontinent and mainly planted to absorb the noise. *Melia dubia* is a fast growing energy crop in India. It is a drought tolerant and can grow in all types of soil with a short gestation period of 2–3 years. It has the ability to provide high yields of biomass and can be harvested multiple times each year.

2.1. Characterization of residues

The selected residues were dried to a moisture content of about 15%. The dried bioresidues were pulverized in a Willey mill to a particle size of less than 1 mm. Properties of the pulverized materials were determined in triplicate and the procedures adopted are given below. Moisture content (ASTM D 3173-87) of the samples was determined by heating the sample in a hot air oven at 103 ± 2 °C up to the arrival of constant weight. The volatile content (ASTM D 3175-89) was found out by heating the sample at 650 °C for 10 min in an oxygen depleted environment. Ash content (ASTM D 3174-89) was determined by heating the sample at 750 °C for 3 h. Fixed carbon was the content that remains after complete volatilization. Heating value of the sample was tested in a bomb calorimeter (Adithya make, India).

Density of the testing materials was determined by the weighed sample occupied in a known volume (Bala, 1997). Elemental composition of the bioresidues was estimated from the proximate analysis (Jigisha et al., 2007). The major constituents of bioresidues consist of cellulose, hemicellulose, lignin and extractives. The cellulose is a high molecular-weight linear polymer of two glucose anhydride units. It is a fiber component comprises about 45–60% of the bioresidues (Updegraff, 1969). The hemicellulose is the second major chemical constituent and usually account for 25–35% of the bioresidue. It is a mixture of various polymerized monosaccharide's and exhibit lower molecular weight than cellulose. The third major component is lignin which lies in the range of 15–40% of bioresidues. It is an amorphous cross-linked phenolic substance and the main binder for the agglomeration of fibrous components (Boerjan et al., 2003). These chemical constituents were determined as per AOAC standards. Thermo gravimetric analysis (TGA Q50) was carried out for the bioresidues at a heating rate of 30 °C min^{-1}. A representative sample from each group was chosen for this analysis. N_2 was used as the purge gas with a flow rate of 60 ml min^{-1}.

2.2. Biooil production system

The biooil production was carried out in a fixed bed pyrolytic reactor. It consists of a reactor, heating and control system and condenser. The diameter and length of the reactor are 50 and 60 mm, respectively. The bioresidue was taken in the reactor and heated electrically at a heating rate of 15 °C min^{-1}. Nitrogen was used as a purge gas at a flow rate of 20 ml min^{-1}. The vapor from the reactor was condensed using a 16 channel copper condenser which was kept in water bath. The quantity of biooil and char (reacted solid residual) were weighed.

The effect of residues constituents on biooil yield was analyzed using Statistical Package for Social Science (SPSS 12.0). In this study, effect of volatile matter and cellulose content on biooil yield was studied by developing the quadratic model.

3. Results and discussion

The results of the study on characteristics of the bioresidues and biooil production are presented and discussed in the following section.

3.1. Characteristics of residues

From the results of the characterization study (Table 1), it is inferred that the volatile matter content was in the range of 58.43–79.14%. The highest volatile matter was found in pinfed computer paper (79.14%). The fixed carbon and ash content was in the range of 7.24–19.79% and 1.60–15.50%, respectively. The composition of cotton stalk and sugarcane bagasse was similar to the results reported by Jenkins (1980); Jenkins and Ebeling (1985). Paper (pinfed computer) had the lowest fixed carbon content of 7.24% and the highest was observed in coconut shell. Cashew nut shell had the lowest density of 231.60 kg m^{-3} and the maximum (792.80 kg m^{-3}) was recorded in saw dust.

From Table 2, it is observed that the carbon content was in the range of 41.62–49%. The bioresidues had hydrogen content of 5.39–6.22%. The oxygen and nitrogen contents were 41.71–46.34% and 0.45–8.23%, respectively. Cellulose, hemicellulose and lignin were in the range of 7–80.5%, 6–39% and 6–45%, respectively

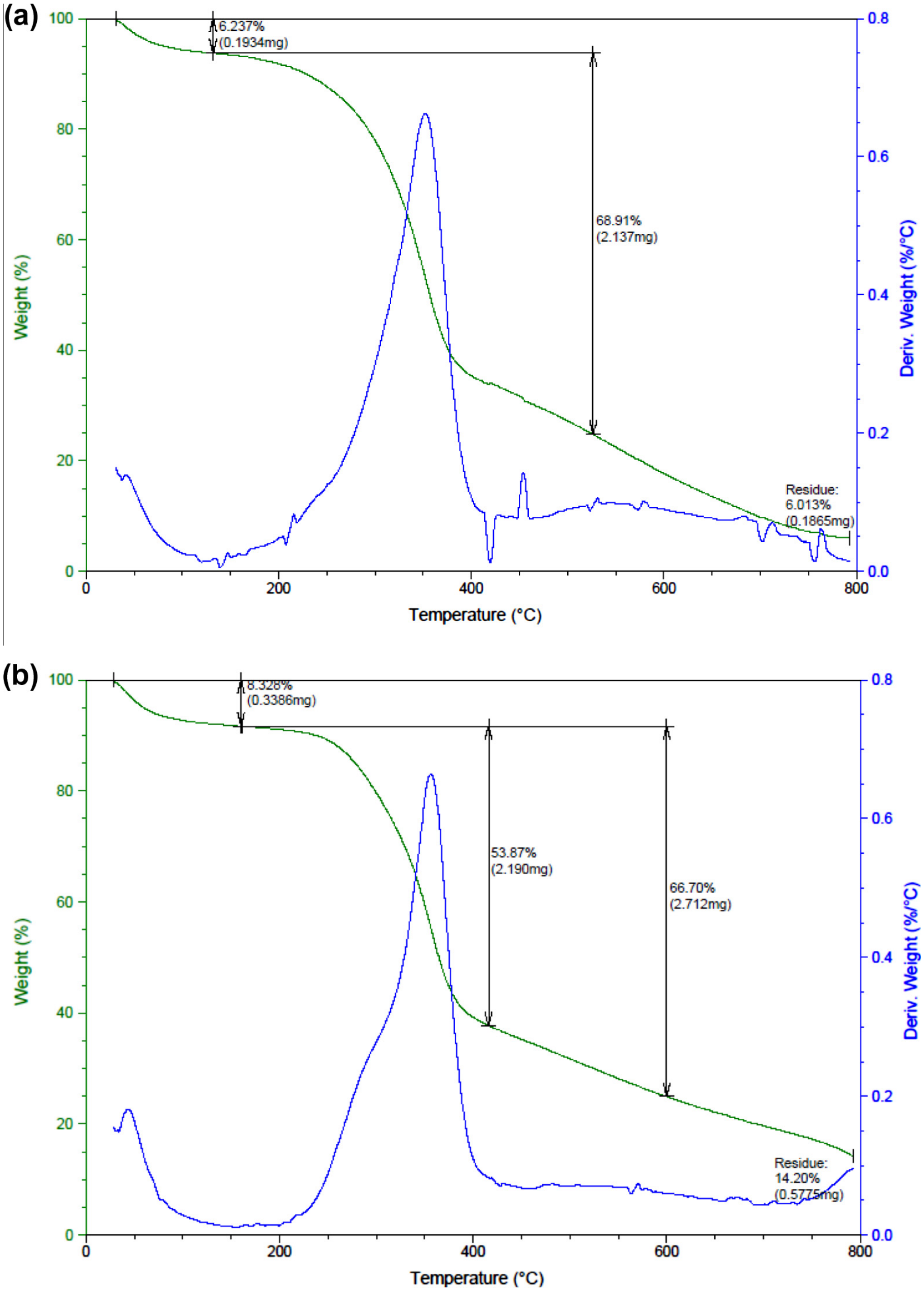

Fig. 1. Thermal decomposition curve of (a) Redgram stalk. (b) Prosopis wood. (c) Tamarind shell. (d) *Melia dubia*.

(Table 3). Paper (pinfed computer) had the highest cellulose content of 80.5%. Saw dust and arecanut stalk had higher lignin (45%) and hemicellulose contents (39%), respectively.

The thermal degradation behavior of the bioresidues is shown in Fig. 1a–d. The initial loss in the decomposition curve corresponds to the release of moisture as vapor from the bioresidues. Beyond this stage, rate of weight reduction was higher up to 400 °C, which may be due to the decomposition of cellulose and hemicellulose. The cellulose and hemicellulose produces more volatile during thermal degradation as reported by Yang et al. (2007). The degradation continued up to 800 °C, but the rate of reaction was minimal which may be due to the degradation of lignin, which contributes more to the formation of char rather than volatiles (Yang et al., 2007). From the TGA curve, it was observed that the degradation was significant up to 400 °C. The process temperature for biooil production would be about 400–450 °C to attain the maximum degradation and volatilization of bioresidues.

3.2. Yield of biooil

The yield of biooil from the selected bioresidues is recorded in Table 4. In this study, the yield of biooil was in the range of 6.33–45%. A maximum yield of 45% was obtained from pinfed computer paper. This may be due to the high cellulose content and volatile nature of the feedstock. Demirbas, 2002 reported biooil yield of 33.6% from wheat husk at 416 °C whereas it

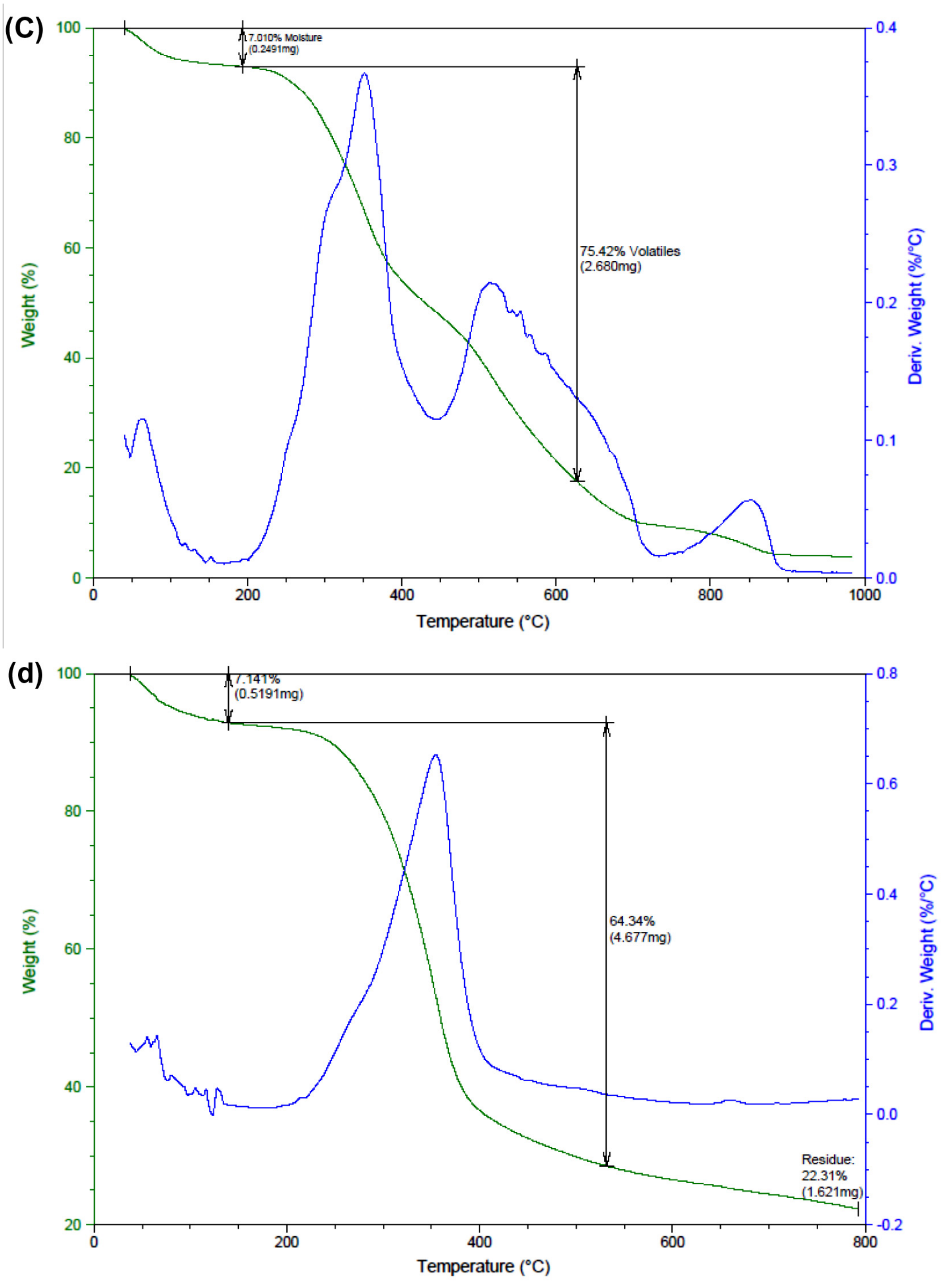

Fig. 1. (*continued*)

was 40.87% in the present study. The increase in biooil yield may be due to the pyrolytic temperature of 450 °C. The biooil yield from spruce wood was reported as 39.7% at 416 °C. In the present study, prosopis yielded 40.90%. The biooil yield from cashew nut shell was 23.5%, which is higher than the yield (20%) reported by Rajesh et al., 2011. Fagbemi et al., 2001 obtained a liquid yield of 35% for wood at 400 °C. The residues with low ash content (3.03–4.57%) such as wheat husk, maize cob, rice husk, *S. saman* fruit and Cumbu Napier grass Co5 produced comparatively more biooil. The same result was reported by Abdullah and Gerhauser, 2008.

3.3. Effect of composition of residues on biooil yield

Regression models were developed to study the effect of moisture, volatile matter, fixed carbon content, cellulose, hemicellulose and lignin on the yield of biooil. This model study revealed that the combined effect of these variables on biooil was insignificant. The R^2 value was 0.028 and 0.068 for the proximate and chemical constituent of bioresidues. From the analysis, it was inferred that the volatile matter and cellulose content had significance on biooil yield. Hence, effect of these parameters was analyzed case by case using curve fit method.

Table 4
Yield of biooil and char from bioresidues.

Sample	Biooil		HHV of biooil (kCal/kg)	Char	
	(g)	%wt		(g)	%wt
Arecanut stalk	3.97 (4.20)	26.47	5437.5	4.43 (2.96)	29.53
Cotton stalk	2.83 (3.80)	18.87	4647.5	5.98 (1.09)	39.87
Redgram stalk	4.63 (1.29)	30.87	5798.1	4.14 (0.87)	27.6
Soybean stalk	2.0 (5.97)	13.33	4031.3	4.72 (0.31)	31.5
Paddy straw	1.91 (6.02)	12.70	4629.1	5.43 (1.49)	36.2
Arecanut husk	1.96 (7.60)	13.10	5914.3	6.0 (1.20)	40.0
Jatropha husk	1.60 (2.13)	10.70	5426.5	5.55 (0.68)	37.0
Rice husk	4.78 (1.90)	31.87	5840.4	5.73 (0.93)	38.2
Wheat husk	6.13 (0.53)	40.87	7728.3	3.62 (0.56)	24.13
Cashew nut shells	3.53 (6.10)	23.50	6908.0	2.86 (4.39)	19.1
Coconut shell	2.12 (1.910)	14.10	4887.9	4.82 (1.60)	32.13
Tamarind shell	2.19 (3.10)	14.60	4730.8	5.14 (0.79)	34.3
Maize cob	5.45 (0.82)	36.33	7358.1	3.92 (3.28)	24.87
Sugarcane bagasse	3.14 (0.65)	20.93	5022.8	3.55 (5.19)	23.7
Coir pith	5.01 (1.40)	33.40	5962.0	3.83 (2.89)	25.53
Saw dust	2.03 (5.43)	13.53	5813.2	3.97 (1.73)	26.47
Cumbu Napier grass Co5	3.85 (3.33)	25.70	5926.8	4.25 (1.02)	28.33
Blue buffel grass	1.91 (1.87)	12.73	8027.0	5.16 (0.61)	34.4
Polyalthia longifolia	1.30 (0.09)	8.70	4826.5	3.54 (2.95)	23.60
Melia dubia wood	1.57 (0.97)	10.47	7682.9	4.11 (1.82)	27.4
Prosopis wood	6.14 (0.12)	40.90	4965.5	4.33 (1.10)	28.9
Samanea saman fruit	3.45 (0.53)	23.00	6750.0	5.0 (0.05)	33.33
Chrorella	1.11 (7.20)	6.40	6206.9	11.42 (5.19)	76.1
Parthenium *hysterophorus*	0.95 (1.50)	6.33	7750.0	4.96 (0.69)	33.1
Pinfed computer paper	6.60 (0.70)	45.00	7024.4	3.93 (0.82)	26.2

The values in parenthesis are standard deviation at 95% confidence interval. Number of determination is 3.

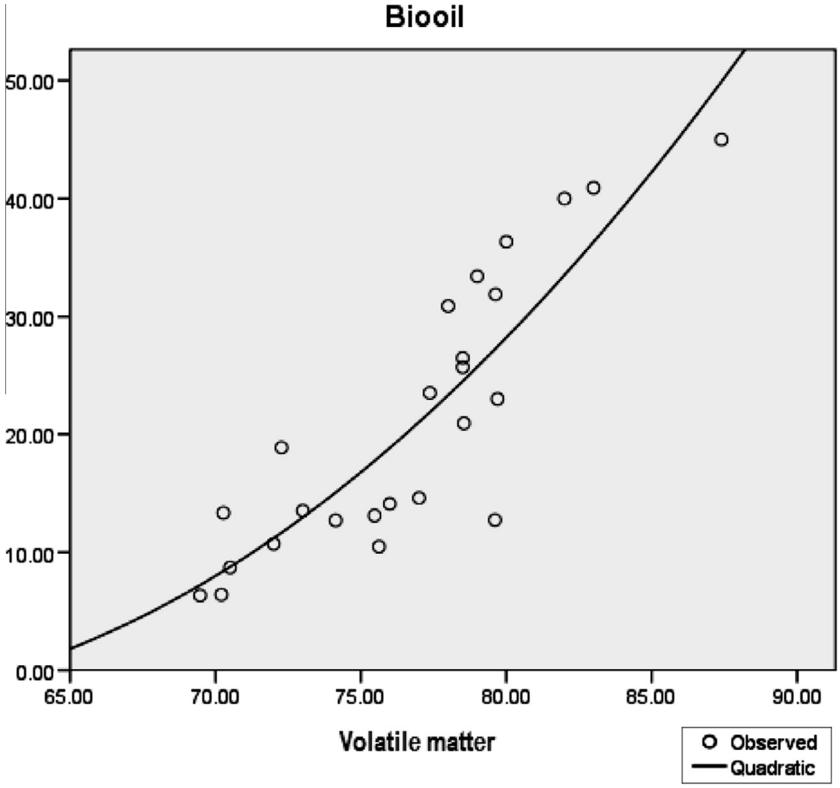

Fig. 2. Curve fit for the effect of volatile matter on biooil yield.

3.4. Effect of volatile matter and cellulose content on biooil yield

The models (Figs. 2 and 3) revealed that the volatile matter and cellulose content had a significant effect on biooil yield with R^2 value of 0.759 and 0.745, respectively at 1% significance level. The empirical model is given below:

$$B = 0.052\ \mathrm{VM}^2 - 5.847\ \mathrm{VM} + 160.23$$

$$B = 0.013\ \mathrm{CE}^2 + 1.892\mathrm{CE} - 21.19$$

where B – Yield of biooil (%), VM – Volatile matter content (%), CE – Cellulose content (%).

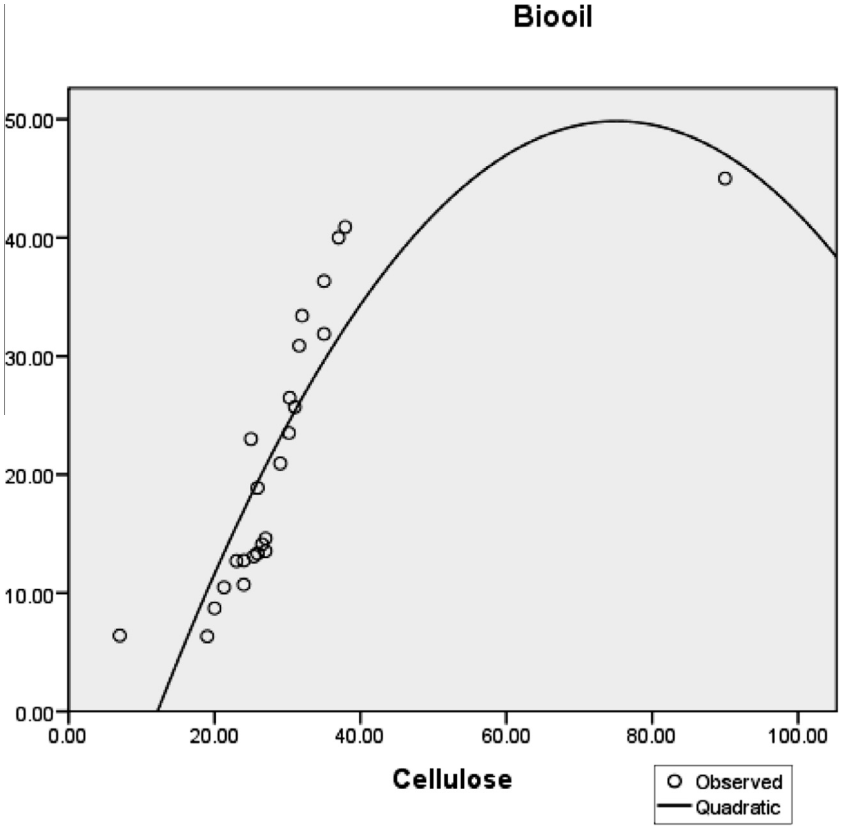

Fig. 3. Curve fit for the control of cellulose content on biooil yield.

The production of volatile matter strongly depends on the thermal degradation of the constituents in the residues mainly from cellulose and hemicellulose. The combined effect of cellulose, hemicellulose and lignin had insignificant effect on biooil yield. This may be due to the degradation temperature by which all molecules may degrade independent of the degree of polymerization. Zbaniotou et al., 2000 reported that the interactions among the components are not of much significance. Among these cellulose and hemicellulose are the two major components that produce volatile matter (Soltes and Elder, 1981). The hemicellulose decomposes at 200–260 °C, which gives more volatiles and lesser tar product. The degradation of cellulose occurs at 240–350 °C and it would be completed at 380 °C which produces, monomeric volatile sugars (Fagbemi et al., 2001; Isa et al., 2011). The lignin is harder to decompose than cellulose since it consists of benzene rings as given by Mckendry (2002); Sharma et al. (2004); Gani and Naurse (2007). As reported by Li et al. (2004); Prins et al. (2006); Yang et al. (2007); Heo et al. (2010) the lignin decomposes slowly over a temperature range of 280–900 °C and mostly yielding char. Meier and Faix (1999) reported that the decomposition of lignin was not significant up to 450 °C that produces only low molecular phenolic groups. According to Kosstrin (1980), the liquid yield is closely related to the cellulose content of the material. The same kinetics was observed by Sadakata et al. (1987) where the liquid product was larger for holocellulose than for other components. In the entire thermal degradation process, C–C linkages will break and the decomposition will be more at 400–450 °C. At this condition, degradation would be maximum and produces more volatiles that increases the biooil yield.

4. Conclusion

Biooil production from 25 bioresidues ranged from 6.33 to 45%. Paper, wheat husk, maize cob, coir pith and prosopis were found to be promising for biooil production. Arecanut stalk, redgram stalk, rice husk, cashew nut shell, sugarcane bagasse and *S. saman* fruit were found suitable for both biooil and char production. Thermal degradation at 400–450 °C resulted in maximum decomposition and produced more volatiles. Volatile matter and cellulose content had major influence on the biooil yield. Biooil produced by this process may be used as fuel in boilers, diesel engines for power generation to replace fossil fuels.

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